EFFECTS OF COMPOSITE LAYER PLATE ON MODAL EXPERIMENTAL ANALYSIS

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ABSTRACT

The composite plates are basic structural components in aerospace, mechanical and civil industries. This project presents the experimental modal analysis of dynamical behavior of plates made up of woven glass fiber and epoxy matrix in free-free boundary conditions. Two composite plates with different number of layers were analysed. The dynamic characteristics observed are natural frequency and mode shape. The result obtained by experimental modal analysis technique for each structure is then compared with the result obtained by using finite element method (FEM). From the results, the influence of number of layers on flexural natural frequencies is investigated. It shows that as the number of layers increase, the natural frequencies also increases. Comparative study is done between the experimental and the finite element result obtained from ALGOR. From the ODS result, it shows that the dominant mode shape for both four and eight layers composite plates are mode 1. The prediction of dynamical behavior plays an important role for their future design applications.

ABSTRAK

Plat komposit merupakan struktur komponen asas dalam industri aeroangkasa, mekanikal dan juga awam. Projek ini membentangkan tentang eksperimen modal analisis bagi mengenal pasti tingkah laku dinamik plat yang diperbuat daripada gentian kaca tenunan dan digabungkan bersama matriks epoksi dalam keadaan sempadan bebas. Dua plat komposit yang mempunyai jumlah lapisan gentian kaca yang berbeza telah dianalisis. Keputusan yang diperolehi daripada eksperimen menggunakan teknik modal analisis bagi mendapatkan kekerapan semula jadi dan bentuk mod bagi setiap struktur kemudiannya dibandingkan dengan keputusan yang diperolehi dengan menggunakan kaedah analisis unsure finite (FEM). Daripada keputusan yang diperolehi, pengaruh jumlah lapisan yang terdapat pada plat komposit memberikan kesan kepada frekuensi semulajadi telah disiasat. Keputusan menunjukkan bahawa semakin banyak lapisan pada plat komposit, semakin tinggi nilai frekuensi yang diperolehi. Selain itu, hasil eksperimen itu disahkan oleh unsur perisian ALGOR. Daripada eksperimen ODS yang dilakukan, keputusan menunjukkan bahawa bentuk mod yang utama bagi empat dan lapan lapisan plat ialah mod 1. Ramalan tingkah laku dinamik memainkan peranan yang penting untuk mengetahui keupayaan plat komposit sebagai struktur dalam sebuah sistem.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

FEA	Finite Element Analysis
FEM	Finite Element Method
DOF	Degree Of Freedom
SDOF	Single Degree Of Freedom
MDOF	Multi Degree Of Freedom
FRF	Frequency Response Function
DAQ	Data Acquisition System
CAD	Computer Aided Diagram
IGES	Initial Graphics Exchange Specification
FFT	Fast Fourier Transform
2D	Two Dimensional
3D	Three Dimensional
SI	International System of Units
UMM	Unit Modal Mass

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Recently, there has been a lot of discussion and review about the role of composite materials as the one of the most common material used in a lot of the growing industries that exists today. Some of the most common use of composite materials in everyday life would be sports equipments, ship building, automobile, and aircraft.

There are many types of composite materials used in the industries. Fiber reinforced composite materials includes glass, carbon, aramid, boron and also ceramics (Tsipas et al, 2012). The fibreglass is one of the types of composite. There are divided further by the types of fibreglass. In this study, the woven fabric composites will be used during the experiments. The application of this woven fabric composites are wide especially in the engineering application. The benefit of using woven fabrics as the reinforcement is that it provides conformability and also excellent integrity for any advanced structural composite application (Mishra et al, 2012).

Since the application of the composite materials are more onto the structures of the automotive, aircraft, shipbuilding and mass transit bodies, subjected widely to dynamic loading that can cause excessive vibration (Velmurugan et al, 2011). To determine the different modes of vibration, the dynamic response of the composite structures need to be understood and studied.

Due to the advancement on the computer aided data acquisition system and instrumentation, it has become more important for the experimentalist to do experimental modal analysis (Sahu et al, 2012). There are many researchers that did the research on the laminated composite laminates, but the research on the dynamic characteristics of the woven fabric composite laminates are still limited.

The method that will be used to test the woven fabric composite would be by modal analysis using the FFT (Fast Fourier Transform) analyzer. This study will involve the experiment on the woven fiber Glass/Epoxy composites plate. The specimen will be in free-free boundary condition form.

The woven fabric composite specimens are fabricated by using the hand-layup technique. The material required for the fabrication of the composite plates are E-glass woven roving which act as the reinforcement (Owens Corning) , Epoxy as the resin and hardener as catalyst.

The composite will have different number of layers. The effect of layers in the composite will be determined by using the modal analysis experiment. The result from the FFT analyzer will then be compared with the Finite Element Method (FEM) tool ALGOR. The results will lead to the natural frequency of each of the different layer composite and the modal shape can be obtained by the ANSYS (Stanciu et al, 2011).

The prediction that the FEM tool ALGOR produce is important when comparing with the FFT result. There should not be much difference in the natural frequency data during the comparison. The study of this dynamic behaviour and characteristics of woven composite plates plays an important role for the future application of this material.

1.2 PROJECT BACKGROUND

Since there are not that many studies directed on the composite materials, the dynamic characteristic of the composite material itself are hard to find.

Composite materials are widely used in a lot of the developing industries today. Some of the industrial sectors that use composite materials are aerospace, automobile, boats, chemicals, domestic, electrical and leisure. In aerospace only will consist of a lot of composite materials such as wings, helicopter blade, landing gears, seats, floors, interior panels, fuel tanks and nose cones (Rawlings et al, 2006).

As stated above, the application of the composite materials is important in many industries. So, in order to gain the valuable information about the dynamic characteristics this study need to be done. The effect that the different geometrical parameters especially the number of layers in the free-free boundary condition of the woven fabric composite plates can be known (Mishra et al, 2012).

1.3 PROBLEM STATEMENT

In recent years, the study about dynamic behaviour of the composite materials has become significant due to the increasing demand in the industries. The natural frequency of the material should be known to prevent any disastrous impact for any engineering structure. Fiberglass material is considered as a safe material to be used, but the damages in the material itself are rather hard to be detected. So, it is really important to know the factors that contribute to the danger that can be catastrophic (Chang et al, 1992). The main reason this study is made is to produce a better understanding of the dynamic behaviour that are made from the woven fiber composite materials especially for the plates. The effects of different number of layer in the composite plates in free-free boundary condition are studied in detail.

1.4 PROJECT OBJECTIVE

The objective of conducting this project is to study the dynamic properties and behaviour of composite layer by using modal analysis and finite element analysis.

1.5 SCOPE OF THE PROJECT

The scope of carrying out this project includes:

i. The analysis of fibreglass composite will be carried out by using Finite element analysis tool ALGOR.
ii. The type of composite use would be fibreglass as the reinforcement and epoxy as the resin.
iii. The experimental result will be obtained by model testing by using impact hammer.
iv. The experimental result and the computational result will be compared.
v. It is the analysis of the natural frequency by using model analysis and FEM on the composite plate to find out the mode shape and natural frequency.
vi. Experimental Operational Deflection Shape (ODS) by motor of 53Hz.
vii. Validation of experimental ODS is done by using calculation and the result is compared.

1.6 GANTT CHART

The Gantt chart is illustrating the project schedule. The starting and finishing week of the project is stated in the chart. It is divided into two rows for each progress. The first row will illustrate the planned period for the element while the second row is the actual period that is done to complete it. The Gantt chart for this particular project can be referred to Appendix A

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the explanation about the project will be stated in detail. It started off with the introduction to the composite materials. Since the composite material itself has many types, the classification of the composite material will be explained further. The main focus would be for the E-glass woven roving which will be used in the experiment.

Other than the explanation on the composite material, there will also be some discussion on the modal analysis itself. Since the experimental investigation will be carried out by using modal analysis technique with the Fast Fourier Transform, DASYLab, impact hammer and also the triaxial accelerometer, the explanation will go deeper in order to give a clear view on how the process will flow and also the connection between all of the elements stated.

Moreover, Finite Element method (FEM) tool ANSYS will also be explain in detail in order to show the function of using this particular software. This tool is needed so that the result can be compared with the FFT analyzer.

2.2 COMPOSITE MATERIALS

2.2.1 Introduction to Composite Materials

Composite material actually can be define as the combination of two or more materials that will eventually produce a product with better properties than those individual components stand alone (Campbell, 2010). It is different than the metallic alloy. This is because the alloys can actually blend the characteristics and properties of two or more metals in order to create a hybrid metal that is more stronger, durable cost-effective than the pure metal. Metal alloys are different from composite materials because there will be subtle changes in the microstructure which will cause dramatic variations in their properties (R. Saravanan et al, 2012).

Composite can be define by a lot of different thing if it is taken at the face value but in the more modern materials engineering, it can be referred to "matrix" material which is reinforced by fibers. By taking Fiber Reinforce Plastic (FRP) as an example, the term indicates that thermosetting polyester matrix that contains glass fibers (Roylance, 2000). Figure 2.1 is showing the laminate fabricated by unidirectionally crossplying reinforced layers in a $0°$-$90°$ stacking sequence.

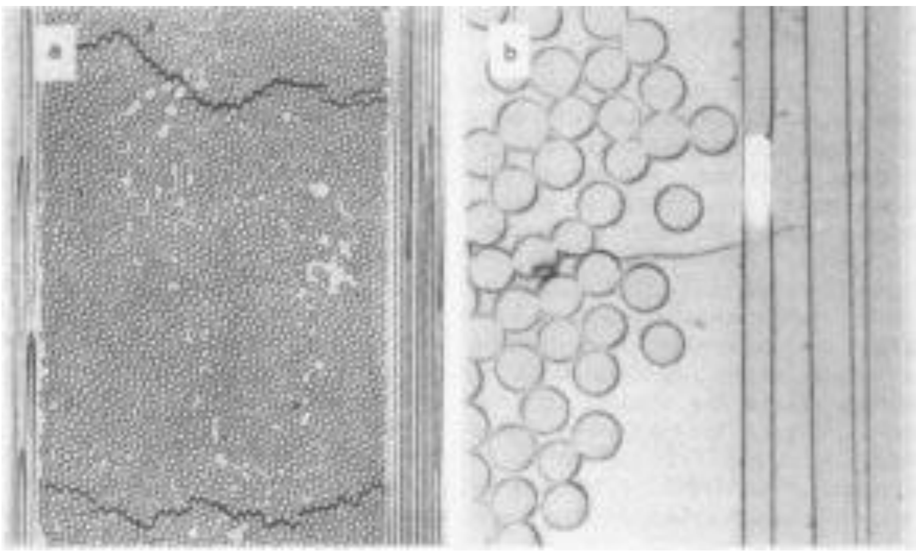

Figure 2.1: A unidirectionally reinforced layers crossplied FRP laminate, shows the microcracking and nonuniform fiber packing.

Source: Harris, B., Engineering Composite Materials, Institute of Metals, 1986.

Composite material is not something that is new to the material engineering. In fact, the first uses of composite went back to the 1500s B.C. It all started when the Mesopotamian and Egyptians used the mixture of straw and mud to build stronger and more durable buildings (Todd Johnson).

2.2.2 History of Composite Materials

The first ever binding materials that were employed to fabricate mortars in ancient buildings would be mud (Moropoulou et al, 2005). This means that composite is not really a new technology. This is because even the bricks that are reinforced with straw and made from mud that were used in ancient civilizations are also considered as composite (Matthews et al, 2006).

The modern composite industry began in 1930, when it is made almost by accident. This happened when an engineer became interested by the fiber formed during the process of applying lettering to a glass milk bottle. Then, in 1937, salesmen from the Owen Corning Fiberglass Company began selling their fibreglass in the United States to the interested parties. This company was formed in 1935 by Owens-Illinois and Corning Glass Works to focus on selling the new fibrous material (Brent Strong, 1989).

The second generation of the composite starts in 1960s where the composite is already called the high performance composite. During this era, a new Saint-Gobain factory in Chambery, France was opened for the production of fibreglass. By 1958, they started to produce composite helicopterblades especially for Alouette II. At the same time, carbon, boron as well as aramid fiber were also introduced to the world. Aramid fiber also known as Kevlar is actually discovered after Kwolek tried to find a solvent to dissolve the nonmelting polymer that she made earlier. This discovery actually proved that the fiber produced from the aramid solution is actually five times stronger than steel. It can be applied to bulletproof vests and helmets (Tim Palucka et al, 2002)

2.3 CLASSIFICATION OF COMPOSITE

2.3.1 Continuous Fiber

Continuous fibers have long aspect ratio. Aspect ratio is the length-to-diameter (*l/d*) ratio. However, continuous fibers can have varied aspect ratio considerably (Rawlings et al, 2006). Continuous fiber composites will usually have the preferred orientation. The orientation of continuous fiber can be seen from Figure 2.2. Some examples of continuous reinforcements include unidirectional, woven cloth and helical winding.

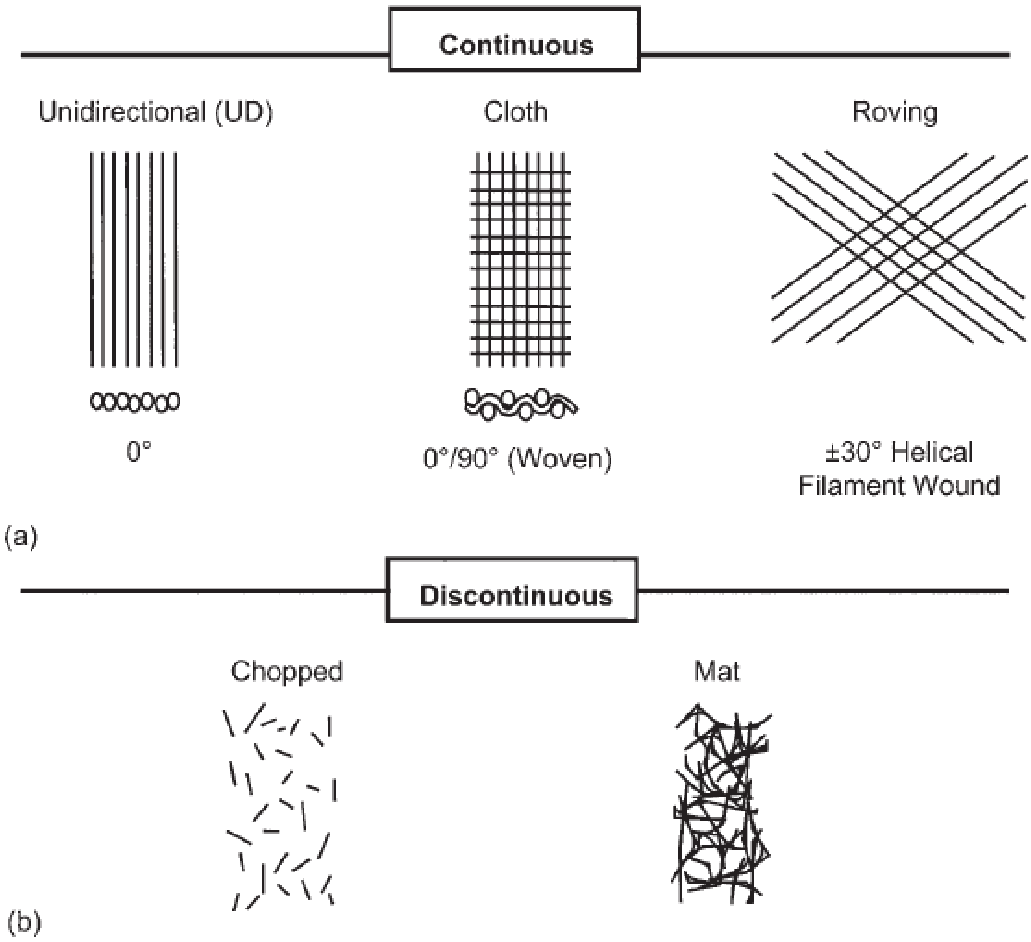

Figure 2.2: Typical reinforcement type: a) continuous fiber; b) discontinuous fiber

Source: F.C. Campbell, 2010.

2.3.2 Discontinuous Fiber

Discontinuous fiber can also be known by particulate composite. Particulate reinforcement may have the dimensions that are more or less equal in all direction. They can come in many shapes including spherical, cubic, platelet, or any irregular or regular geometry (Rawlings et al, 2006).

Comparing to the continuous fiber, particulate seems to be much weaker and less stiff, but they are not as expensive as the continuous fiber. Discontinuous fiber have short aspect ratio and they usually have random orientation (Matthews et al, 2006). Examples of discontinuous fiber are chopped fibers and random mat which can be seen in Figure 2.3.

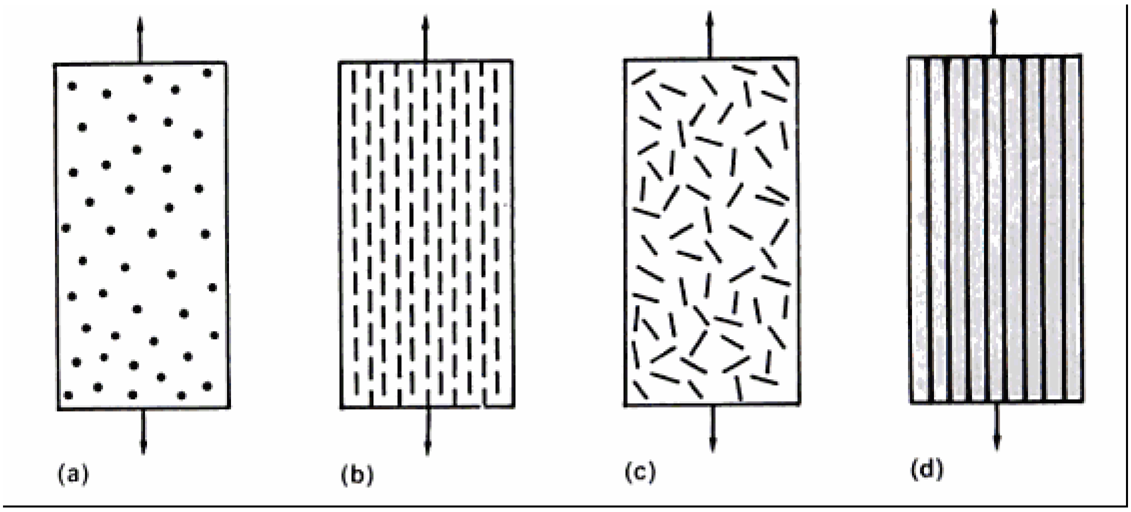

Figure 2.3: Example of composites: a) particulate, random; b) discontinuous fibres, unidirectional; c) discontinuous fibres, random; d) continuous fibres, unidirectional.

Source: Frank L. Matthews, Rees D. Rawlings, 2006.

2.4 COMPOSITE FABRICATION PROCESS

2.4.1 Basic Hand Lay-up Technique

It is normally done in a Fibre Reinforced Plastic (FRP) mould that are polished on the inside part. There is no limit when it comes to the mold. Some may be as simple as flat surface or some may have infinite edges and curves (Brandon Lee, 2004). Figure 2.4 shows the basic hand lay-up technique.

Hand lay-up is considered as the simplest and oldest way used to produce reinforced plastic laminates. The capital investment for using this method is relatively low comparing to other method. For simplicity, some fabricators may used brush or simply pour the resin into the molds if spray gun is not available. Spray gun is the most expensive equipment for hand lay-up process, but it is optional to do so (American Composite Manufacturers Association, 2004).

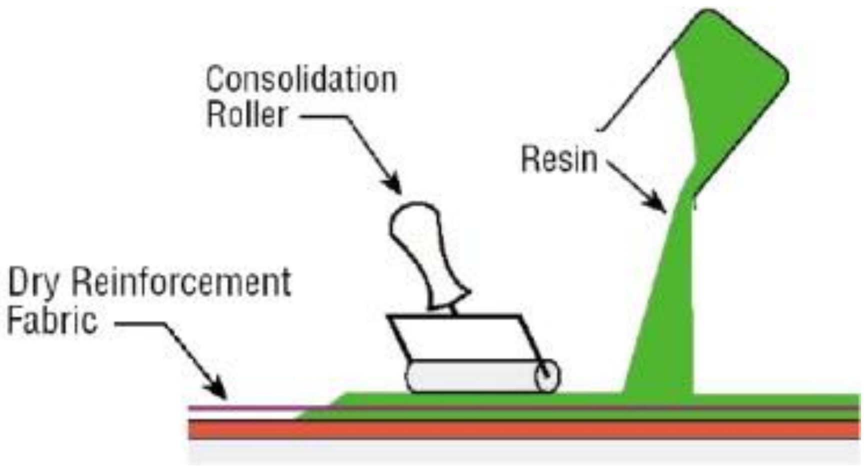

Figure 2.4: Basic concept in using the hand lay-up technique.

Source: J.R. Vinson, R.L. Sierakowski, 2008.

The very first step to do the hand lay-up is preparing the mold for the composite to be applied on. The mold should be clean and free from any surface deformation or particulate because it can affect the final surface condition of the composite itself. Check the mold from chips and blemishes.

Next step is applying the releasing agent on the surface of the mold so that the composite can be released easily after curing (Brandon Lee, 2004). Releasing agent is actually a non-binding polymer or a wax that is first coat to the mold. This releasing agent can ensure easier release and pop out of the finished cured part from the mold (Todd Johnson). Some examples of releasing agents are poly vinyl alcohol (PVA), hard wax and fluorocarbons (Keith Godber, An Overview of Release Agent Types and Technology).

Resin is another important part in making composite. Resin will hold everything together while transferring the loads that are applied on the composite through the fibers to the rest of the structure. Other than the purpose of binding the structure, resin will also protect it from any kind of corrosion, abrasion, impact and also environment factors (Fibermax Composites, 2007). Among the most commonly used resin would be Polyester (orthophthalic and isophthali), epoxy, phenolic and also vinyl ester. The mixture of resin and the catalyst should be in the correct quantity which is between $1{}^{1}/{}_{2}$ - 2% when comparing by the weight (Basic Hand Lay-up Techniques For Reinforced Composites).

Ideally, the lay-up process of the fibreglass reinforcement should start as soon as the mixture of resin is ready (Basic Hand Lay-up Techniques For Reinforced Composites). This is because if the time lapse between the lay-up and mixing the resin is too long, the resin will hardened before it could reached the fiber. This can produce a low quality composite as a final product. The hand lay-up process can be done by using brush or even spray gun (American Composite Manufacturers Association, 2004). From Figure 4, it can be seen that a roller is used to take out all of the air bubbles from the laminate to ensure even resin deposited and no air bubbles in the composite.

The curing part of the hand lay-up technique is done after the fibreglass reinforcement and resin finished. The curing time for different composite may varied according to the size, thickness and type of composite. The curing may be as fast as two hours or it could even be cured overnight. Upon curing, the composite can be trimmed according to the desired size and shapes (Beckwith, 2009) as shown in Table 2.1.

Table 2.1: Machining composites – Trade to be considered

Topic	*Best Practices or Reason*
Tool Sharpness	• Keep all machining, drilling and cutting tools sharpened to reduce fuzzing, pitting, fraying and delamination
Coolant Use	• Reduces heat buildup in resin, controls dust and minimizes particulate damage
Backup Materials	• "Rigidize" thinner composite sections: ○ Masonite or aluminum stock ○ Plywood ○ Teflon or rigid plastics
Post-process Cleaning	• Rinse parts afterwards with water, solvents or appropriate materials
Overheating	• Overheating causes potential damage scenarios: ○ Fiber-resin microcracking ○ Delaminations at edges ○ Resin thermal degradation of mechanical properties ○ Unacceptable color changes (cosmetic loss)
Dust Collection	• Always use dust collectors for "dry" operations
Electrical Motor Protection	• Protect CNC electric motors, computer control systems, other electrical devices from carbon fiber dust: ○ Carbon fiber highly conductive – shorts out electrical systems ○ All reinforced fiber/resin dust unacceptable around secondary painting operations
Machining Speeds and Feed Rate	• Select machining speeds, drilling rates and feed rates appropriate for the materials used (note that aramid behaves very different from carbon and glass composites)

Source: W. Beckwith, 2009.

2.5 FINITE ELEMENT METHOD

2.5.1 Introduction

Finite element method (FEM) is a method that uses numerical to solve integral or differential equation. A lot of physical problem has applied to this method